



UNIVERSIDADE CATÓLICA PORTUGUESA

# Transition Toward Sustainability: Can Open Innovation Practices Provide The Solution

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Católica Porto Business School

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by

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# Resumo

A sustentabilidade ambiental tornou-se uma prioridade fundamental para as empresas do setor industrial, levando-as a procurar novas formas de inovar. Esta dissertação analisa de que forma a Inovação Aberta pode contribuir para melhorar a sustentabilidade ambiental dos processos produtivos. Através de entrevistas com gestores de empresas industriais portuguesas de diversos setores, o estudo explora a tipologia da Inovação Aberta Sustentável e analisa o papel dos intermediários de conhecimento e das capacidades dinâmicas no apoio a estas práticas de inovação.

Os resultados demonstram que muitas empresas colaboram com parceiros externos para aceder a tecnologias verdes, reduzir custos e desenvolver produtos ecológicos. Estas colaborações conduzem frequentemente ao desenvolvimento de novos produtos sustentáveis, ao reforço da reputação da marca e à entrada em novos mercados. No entanto, as empresas enfrentam também desafios, como a escassez de recursos, dificuldades na proteção do conhecimento partilhado e instabilidade nos mercados.

Este estudo combina enquadramento teórico com evidência prática, demonstrando como a Inovação Aberta pode apoiar os objetivos de sustentabilidade no setor industrial. São apresentadas recomendações úteis para empresas que pretendam adotar práticas de inovação colaborativa com vista a uma atuação mais responsável a nível ambiental.

Palavras-chave: sustentabilidade, inovação aberta, inovação aberta sustentável, intermediários de conhecimento, capacidades dinâmicas, manufatura



# Abstract

Environmental sustainability is becoming a key priority for manufacturing companies, leading companies to explore new ways to innovate. This thesis examines how Open Innovation can help improve the environmental sustainability of production processes. Through interviews with managers from Portuguese manufacturing firms from various sectors, the study explores the typology of Sustainable Open Innovation and looks at the role of knowledge intermediaries and dynamic capabilities in supporting these innovation practices.

The results show that many companies work with external partners to gain access to green technologies, reduce costs, and develop eco-friendly products. These collaborations often lead to new sustainable products, stronger brand reputation, and access to new markets. However, companies also face challenges such as limited resources, difficulty protecting shared knowledge, and market instability.

This study combines theory with real-world insights to show how Open Innovation can support sustainability goals in manufacturing. It offers useful recommendations for companies aiming to become more environmentally responsible through collaborative innovation.

Keywords: sustainability, open innovation, sustainable open innovation, knowledge intermediaries, dynamic capabilities, manufacturing



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# Abbreviations

SMEs: Small and Medium Enterprises

R&D: Research and Development

OI: Open Innovation

NPD: New Product Development

SOI: Sustainable Open Innovation



# 1. Introduction

The growing global concern for sustainability has redefined the way organizations approach innovation and value creation, driven by environmental crisis, resource scarcity and growing societal expectations. As industries strive to minimize their ecological footprint, many firms have shifted from closed, internally driven Research and Development (R&D) models toward more collaborative and externally integrated innovation strategies. This transition enabled firms to minimize their environmental footprint while maintaining economic value (Chesbrough & Crowther, 2006). This constant need to achieve sustainable goals has popularized a strategic paradigm that emphasizes innovative practices and, to some extent, new business models.

Open Innovation (OI) was first conceptualized in 2003, from studies of Professor Henry Chesbrough, who described it as active collaboration and idea exchange both inside and outside of organizational boundaries (Slotegraaf, 2012). A key benefit of OI lied in its ability to enhance New Product Development (NPD) by leveraging external partnerships, thereby accelerating technological advancements and sustainability-driven innovation (Watanabe et al., 2011). Later studies indicated that OI presents substantial prospects for expansion and advancement in conventional sectors, including manufacturing (Markham & Lee, 2013).

Next, an additional main reason for adopting OI was the constant social and environmental push towards sustainable business activities, that prioritizes the adoption of economic, social, and environmentally sustainable strategies. This asserts that organizations with strong orientation are more likely to adopt OI practices (Radnejad et al., 2017). Despite concerns that OI may lead to market

saturation by fast followers, its dynamics foster continuous growth, ultimately enhancing an organization's sustainable development (Yun et al., 2022).

While existing research highlights the potential of OI for sustainability, there remains a gap in understanding the effectiveness of OI strategies in manufacturing firms (Obradović et al. 2021). Closing this gap is essential for developing a comprehensive framework that integrates OI with long-term environmental objectives, advancing both academic research and real-world sustainability practices.

Therefore, the present study aims to address the subsequent research question: How can OI practices enhance the environmental sustainability of production processes? This inquiry explores the connections between OI practices and sustainability through semi-structured interviews to leaders of companies in Portuguese manufacturing sector. By addressing the current standard and offering practical study cases, it provides practical insights for manufacturing firms seeking to integrate OI-driven sustainability strategies, while also deepening our understanding of the relationship between OI and sustainability, emphasizing the potential for systemic change in low-tech industrial sustainability standards.

The next section reviews literature on the evolution of OI and sustainability, with a focus on manufacturing. The section will delve into historical trends, key milestones, and influential theories that have shaped the understanding of OI in this context. Additionally, it will discuss case studies and empirical evidence highlighting successful implementations of OI strategies that promote sustainability, as well as challenges and opportunities faced by manufacturers in integrating these approaches.

## 2. Literature Review

The present literature review aims to shed light on the standing connection between OI and sustainability in manufacturing, uncovering the interactions between stakeholders and focusing on the interdisciplinary nature of knowledge intermediaries and dynamic capabilities. The theoretical conversation we are joining revolves around the integration of OI and sustainable manufacturing practices, characterized by the collaborative approach to innovation and the adoption of environmentally friendly production.

### 2.1. Evolution of OI and Sustainability in Manufacturing

Historically, innovation in manufacturing followed a closed R&D model that relied heavily on internal capabilities and secrecy. This model was dominant throughout the 20th century but began to erode under the pressures of globalization, rising innovation costs, and increasing technological complexity. As these limitations became more apparent, firms were compelled to seek more collaborative approaches to innovation (Chesbrough & Crowther, 2006; Obradović et al., 2021).

The emergence of OI, as coined by Henry Chesbrough in 2003, redefined the innovation landscape by promoting purposeful knowledge flows across organizational boundaries. In manufacturing, this model has proven particularly transformative, shifting innovation from firm-centric processes to network-based ecosystems where value is co-created with a variety of stakeholders, including

suppliers, universities, startups, and even competitors (Watanabe et al., 2011; Markham & Lee, 2013; Obradović et al., 2021).

OI fosters rapid problem-solving, wider experimentation, and the integration of external expertise, which is crucial for sustainability-driven innovation. Firms like General Mills and Procter & Gamble, two multinational corporations that produce and sell consumer goods, exemplify the strategic use of OI to co-develop environmentally sustainable solutions (Slotegraaf, 2012). These practices demonstrate that leveraging external partnerships does not diminish innovation capacity but strengthens it through accelerated access to complementary knowledge and emerging technologies (Leung, 2010).

This shift also reflects a broader transformation in industrial logic, where knowledge becomes both input and output in value creation processes. Particularly in high-impact sectors, traditional internal R&D often lacks the interdisciplinary reach necessary to address complex sustainability challenges, positioning OI as a viable mechanism for environmentally conscious innovation (Chesbrough & Crowther, 2006).

Sustainability pressures, ranging from environmental degradation to regulatory mandates and shifting consumer expectations, have significantly influenced manufacturing strategies. These external drivers have catalyzed a shift toward circular and resource-efficient production models, in which OI serves as a facilitator of systemic transitions (Radnejad et al., 2017; Obradović et al., 2021). In this context, firms increasingly collaborate with NGOs, government bodies, and research institutions to develop technologies like carbon capture systems and biodegradable materials (Watson et al., 2018; Kimpimäki et al., 2022).

The collaborative principle of OI enhances not only technical capacity but also legitimacy and institutional alignment. Multi-actor platforms, such as innovation consortia and meta-organizations, help diffuse innovation risks, align private incentives with public goals, and embed sustainability within sectoral

norms (Radnejad et al., 2017; Kimpimäki et al., 2022). These platforms are particularly critical for small and medium enterprises (SMEs), which often lack internal R&D depth but can access external knowledge to reduce eco-innovation risks (Du et al., 2016; Farjam et al., 2023; Purdy et al., 2023).

Fernández et al. (2021) introduced the concept of a "double-pressure system", where firms are simultaneously influenced by top-down regulations and bottom-up market demands. This dual force compels firms, especially in developing economies, to integrate sustainability through OI frameworks as both a compliance measure and a competitive strategy.

The COVID-19 pandemic served as a pivotal moment, exposing the fragility of global supply chains and underscoring the need for adaptability and sustainability. Gross (2020) argues that this disruption forced companies to reevaluate their innovation strategies, turning to OI for resilience and flexibility. Digital integration, transparency, cross-sectoral collaboration, traits of open science, became central tenets of post-pandemic innovation (Smart et al., 2019).

Yun et al. (2022) introduce the concept of "inter-rationality", describing how firms oscillate between openness and closure based on regulatory environments and market signals. This cyclical engagement enhances responsiveness and enables iterative refinement of sustainable solutions. Digital tools and platforms, such as online hackathons, open calls, and knowledge repositories, support this by enabling real-time collaboration and experimentation (Slotegraaf, 2012; Watson et al., 2018).

The pandemic also reinvigorated public-private partnerships and transition intermediaries. These actors, ranging from research institutions to local governments, took active roles in mission-driven innovation, aligning OI practices with systemic sustainability goals (Caloffi et al., 2023; Sandoval Hamón et al., 2024). These hybrid governance models enhance inclusion and resilience within innovation ecosystems.

Moreover, the integration of Industry 4.0 technologies such as artificial intelligence, internet of things, and blockchain, has further expanded the potential of OI in supporting sustainability. These technologies enable decentralized collaboration, real-time environmental monitoring, and increased traceability, thereby aligning digital transformation with eco-efficiency (Lee et al., 2014; Obradović et al., 2021). Smart manufacturing platforms and open data systems facilitate interdisciplinary knowledge exchange, crucial for addressing multifaceted environmental issues.

Digital OI has also democratized participation in sustainability innovation. Citizens, startups, and civil society organizations now play a role in product co-creation and problem-solving. Companies like General Mills' G-WIN, Nike's NIKEiD, Lego's Design by Me, Starbucks' My Starbucks Idea, and Dell's IdeaStorm have embraced this approach and often develop a specific portal for collaborations, as documented by Slotegraaf (2012). Next, platforms such as Innocentive and NineSigma, exemplify this trend, acting as innovation intermediaries that match sustainability challenges with global pools of expertise.

These tools also support lifecycle assessment and predictive analytics, allowing firms to optimize sustainability performance across their value chains, from raw material sourcing to end-of-life recycling (Lee et al., 2014; Watson et al., 2018; Obradović et al., 2021).

Traditionally closed high-tech clusters and science parks are also evolving into sustainability-oriented ecosystems. Hybrid governance involving universities, firms, and public institutions now supports the development and diffusion of green technologies (Sandoval Hamón et al., 2024). These entities function as OI platforms under sustainability missions, using mechanisms like co-patenting and equity crowdfunding to foster eco-innovation (Troise et al., 2021; Ponta et al., 2022).

Transition intermediaries coordinate stakeholder alignment and knowledge sharing across sectors, enhancing the scale and impact of sustainable innovation (Caloffi et al., 2023). As firms blur disciplinary boundaries, they access more diverse insights, increasing the robustness and replicability of sustainability solutions.

In summary, the evolution from closed innovation systems to sustainable OI ecosystems signals a strategic realignment in manufacturing. Sustainability is no longer a secondary consideration, but a core element embedded in innovation strategies. OI enables firms to integrate external expertise, build dynamic capabilities, and foster system-wide transitions toward environmentally resilient production. This shift is both operational and institutional, requiring shared responsibility, governance capacity, and technological readiness across all levels of industrial ecosystems.

## 2.2. Typology of Sustainable OI

OI encompasses a set of practices in which firms leverage external and internal ideas to accelerate innovation and expand their markets. In the context of environmental sustainability, Sustainable Open Innovation (SOI), emerges as a purposeful integration of sustainability principles into OI frameworks. This chapter explores the conceptualization and typology of SOI, distinguishing its three dominant modes, inbound, outbound, and coupled innovation, and explicitly highlights their roles in enhancing environmentally sustainable manufacturing.

SOI is defined as the intentional and managed integration of knowledge flows between organizations and their stakeholders to develop innovations that address environmental, social, and economic sustainability goals (Kimpimäki et al., 2022). The concept of SOI, acknowledges that firms cannot address the

complexity of sustainability challenges in isolation and thus require collaborative mechanisms to exchange knowledge, reduce innovation costs, and mitigate ecological impacts.

Troise et al. (2021) and Ponta et al, (2022) illustrate how collaborative innovation platforms, including co-patenting and equity crowdfunding, have become key enablers of SOI, especially in industries where sustainability imperatives and market competitiveness intersect like agri-foods. Kimpimäki et al. (2022) differentiate between Open Social Innovation and Open Sustainable Innovation by the focus of each one, and emphasizes that both models contribute to aligning systemic sustainability goals with organizational innovation practices.

While the core mechanisms of SOI mirror those of traditional OI, what distinguishes SOI is its normative orientation, specifically, its alignment with long-term ecological objectives, circular economy principles, and the development of environmentally beneficial technologies. Fernández et al. (2021) argue that SOI manifests both as resource-efficiency innovations, which seek to minimize material and energy usage, and sustainable sensitiveness innovations, which embed environmental values into product design and business models.

### 2.2.1. Sustainable Inbound Innovation

Inbound innovation involves sourcing external ideas, technologies, and knowledge to enhance a firm's internal R&D efforts. When applied to sustainability, it allows firms to integrate environmentally relevant expertise into their R&D pipelines, supporting the creation of greener processes, services and products.

Chesbrough & Crowther (2006) describe inbound OI as a strategy for firms to “leverage the discoveries of others,” reducing time-to-market and

development costs. This is particularly valuable in sustainability contexts where rapid adaptation is necessary. Research shows that sustainability-oriented cultures are combined with externally sourced knowledge, firms show improved NPD outcomes, especially regarding environmental performance (Du et al., 2016).

Slotegraaf (2012) exemplifies this with the cases of General Mills and Procter & Gamble, which have adopted inbound OI practices solely to develop sustainable innovations through collaboration with suppliers, customers, and research institutes. Similarly, a study performed on Chilean manufacturers provides evidence that external collaborations, especially with academic institutions and consultants, lead to successful eco-innovation outcomes, even in settings with limited internal R&D capabilities (Fernández et al., 2021).

However, sustainable inbound innovation also poses challenges. (Purdy et al., 2023) caution that the failure to align external knowledge with internal absorptive capacity can increase the likelihood of project termination. This highlights the importance of strategically managing the connection between inbound knowledge and internal capabilities to accomplish sustainable goals.

### 2.2.2. Sustainable Outbound Innovation

Outbound innovation refers to the externalization or commercialization of internal ideas, processes and technologies. In sustainable contexts, it allows firms to share or license environmentally beneficial innovations that may not align with their current business model, thus amplifying their positive environmental impact.

As outlined by Chesbrough & Crowther (2006), outbound OI enables firms to avoid wasting underutilized innovations by transferring them to other organizations capable of commercializing them effectively. This approach is

particularly relevant in sustainability, where innovations, such as clean technologies or energy-efficient processes, can generate greater environmental value when diffused across industries.

By licensing such technologies or engaging in joint ventures, firms not only monetize their innovations but also contribute to sector-wide sustainability transitions. For example, a manufacturing company developing a closed-loop recycling system may license this innovation to industry peers, encouraging broader adoption of circular economy practices.

Outbound innovation further supports knowledge spillovers, enhancing collective environmental learning across sectors. Yet, it demands careful intellectual property management and partner alignment to ensure that environmental benefits are not undermined by commercial competition or misuse (Yun et al., 2022).

### 2.2.3. Sustainable Coupled Innovation

Coupled innovation integrates both inbound and outbound knowledge flows through structured collaborations such as alliances, public-private partnerships, and consortia. This model is particularly effective in addressing complex, systemic sustainability challenges that surpass the problem-solving capacity of individual firms.

Radnejad et al. (2017) provide a compelling example in the oil industry, where meta-organizations enabled firms to pool resources, conduct joint R&D, and co-develop sustainability solutions. Similarly, Leung (2010) earlier described how Canadian forest product manufacturers engaged in coupled innovation through initiatives promoting energy self-sufficiency and renewable material sourcing.

Troise et al. (2021) further expand the concept of sustainable coupled innovation through the lens of equity crowdfunding, showing how investors contribute both financial and knowledge-based inputs to co-create sustainability innovations in agri-food manufacturing. These platforms demonstrate how firms can co-design environmentally and socially responsible innovations with stakeholders who also assume governance roles.

From a systems perspective, coupled innovation allows for dynamic, iterative knowledge exchange, which is particularly valuable in long-term sustainability transitions. However, as Toroslu et al. (2023) highlight, these collaborations can also be resource-intensive and delay key performance milestones. This reinforces the need for careful design of inter-organizational governance and capability alignment when adopting coupled SOI strategies.

## 2.2.4. SOI Knowledge Intermediaries and Dynamic Capabilities

Achieving environmental sustainability through OI in the manufacturing sector requires more than merely adopting external knowledge. Fundamentally, it relies on enabling mechanisms that mediate, channel, and absorb such knowledge across organizational boundaries. Within this context, knowledge intermediaries and dynamic capabilities emerge as critical components of effective SOI strategies. This chapter examines these two interrelated constructs, explores their roles in facilitating sustainability transitions, and presents empirical and conceptual evidence of their impact on innovation performance in manufacturing.

Knowledge intermediaries are organizations or platforms that facilitate the flow of knowledge between multiple actors within innovation ecosystems.

Unlike traditional consultancies or service providers, they act as neutral brokers that enable collaborative learning, coordinate multi-stakeholder innovation processes, and align interests across diverse institutional logics (Meissner & Shmatko, 2017). Through the Knowledge Triangle framework, Meissner and Shmatko highlight the role of such intermediaries as gatekeepers who curate and translate knowledge across education, research, and innovation domains. These partners actively shape innovation trajectories by determining which technologies are scaled, which partnerships are pursued, and which environmental objectives are prioritized.

Supporting this, the Triple and Quadruple Helix models (Marchesani & Ceci, 2025) conceptualize innovation as a result of interaction between government, industry, academia, and civil society. In these models, intermediaries, such as universities, incubators, or smart city platforms, function as interfaces between helices, translating complex knowledge into applicable innovations and reducing fragmentation across sectors.

Empirical research reinforces the significance of intermediaries in sustainability transitions. Tödting et al. (2009) found that in Austrian manufacturing sectors, innovation performance significantly improved when mediated by regional research organizations and universities, especially in environmental innovation. Watson et al. (2018) emphasize that intermediaries also develop stakeholder engagement capabilities, allowing firms to connect with external expertise while managing legitimacy, complexity, and alignment.

Recent work by Caloffi et al. (2023) introduces the concept of transition intermediaries, a specialized subset of innovation intermediaries focused on enabling systemic, sustainability-driven change. Transition intermediaries engage in foresight, cross-sectoral learning, and even rule-breaking or rulemaking to facilitate socio-technical transformation. By doing so, they lower the transaction costs of collective action and enhance the credibility of green innovation efforts.

Sandoval Hamón et al. (2024) demonstrates how science and technology parks increasingly operate as sustainability-oriented ecosystems, fostering university–industry collaborations, facilitating green technology transfer, and enhancing regional environmental resilience. These platforms help SMEs and manufacturers embed sustainability knowledge into their innovation processes, especially when internal R&D capacity is limited.

Further illustrating knowledge intermediation, the Quadruple Helix model has been applied to smart city innovation ecosystems, where strong collaborations among government, academia, industry, and civil society help drive both digital transformation and environmental innovation (Lee et al., 2014; Marchesani & Ceci, 2025). These collaborations institutionalize sustainability principles and enable participatory knowledge sharing, positioning cities themselves as innovation intermediaries.

Dynamic capabilities determine whether firms can absorb, adapt, and deploy that knowledge effectively. As defined by Watson et al. (2018), dynamic capabilities refer to a firm's ability to “integrate, build, and reconfigure internal and external competencies” in response to shifting environments. They distinguish between:

- i) First-order capabilities – Managing relationships with external stakeholders.
- ii) Second-order capabilities – Reframing sustainability challenges and developing new co-created solutions.

Zhang et al. (2023) emphasize that dynamic capabilities support firms in restructuring business models, responding to regulatory shifts, and effectively integrating external sustainability knowledge into their core operations. This is particularly important for addressing eco-efficiency goals and aligning firm strategy with long-term environmental value creation.

Adding further nuance, Yun et al. (2022) introduce the theory of inter-rationality, wherein firms alternate between openness and closure in their innovation activities depending on external signals and internal readiness. This

theory presents a cyclical model of OI that enhances resilience by allowing firms to shift engagement levels based on the stage of the innovation process, regulatory climate, or stakeholder needs.

Firms with robust dynamic capabilities are thus better equipped to manage the ambiguity, complexity, and coordination demands typical of sustainability transitions (Zhang et al., 2023). For example, SMEs, despite limited R&D capacity, can thrive through the development of absorptive capacity, allowing them to identify, assimilate, and apply external environmental knowledge (Silva et al., 2021; Purdy et al., 2023), making a learning-oriented culture and external search practices key enablers in this regard.

The combination of knowledge intermediary support and internal dynamic capabilities has been shown to significantly influence sustainability-oriented innovation outcomes. Obradović et al. (2021) present several empirical cases from manufacturing:

Digital Innovation Hubs in Italy act as knowledge brokers, facilitating SMEs' green and digital transformation, especially in food and machinery sectors. These hubs provide access to digital tools and sustainability experts, supporting both knowledge acquisition and internal absorption.

In pharmaceutical manufacturing, public–private partnerships function as collaborative innovation ecosystems, using Industry 4.0 tools to co-develop sustainable solutions such as low-carbon packaging and green chemistry methods.

Multi-actor ecosystems comprising firms, NGOs, and universities have tackled circular economy challenges, developing waste reduction technologies and eco-design strategies through co-creation and shared governance.

These examples illustrate that implementing SOI requires not only technological capability and institutional support, but also the governance capacity to manage complex knowledge flows and the organizational agility to

act on them. Firms embedded in such ecosystems, and equipped with dynamic capabilities, are more likely to realize environmental benefits from OI initiatives.

<b>Theme</b>	<b>Theory/Framework</b>	<b>Key References</b>	<b>Key Role in OI for Sustainability</b>
<b>Knowledge Intermediaries</b>	Triple/Quadruple Helix	Meissner & Shmatko (2017), Marchesani et al. (2025)	Facilitate systemic, cross-sector knowledge flows
	Innovation Intermediary Typologies	Caloffi et al. (2023)	Matchmaking, governance, coordination in sustainable innovation
	Knowledge Triangle	Meissner & Shmatko (2017)	Link academia, industry, and innovation
	Smart Cities as Intermediaries	Lee (2014), Li (2025), Sandoval (2024)	Urban platforms for sustainability co-creation
<b>Dynamic Capabilities</b>	Dynamic Capabilities View (DCV)	Zhang (2023), Yun (2022), Fernández (2021)	Enable innovation reconfiguration under environmental pressures
	Absorptive Capacity	Purdy (2023), Du (2016), Fernández (2021)	Facilitate effective use of external environmental knowledge
	Inter-rationality	Yun et al. (2022)	Guide strategic openness based on learning cycles
	Collaborative Capabilities	Radnejad (2017), Troise (2021), Toroslu (2023)	Support co-creation in complex sustainability initiatives

*Table 1 - Key Theories of Knowledge Intermediaries and Dynamic Capabilities in SOI*



## 3. Methodology

Given the exploratory nature of this research and its aim to derive theoretical and practical insights, a qualitative research design was employed, combining an extensive literature review with empirical data collection through semi-structured interviews. To ensure methodological coherence and rigor, the study adopts the Gioia Methodology (Magnani & Gioia, 2023), which is particularly suited for investigating complex, dynamic phenomena where new theoretical insights are expected to emerge from field data, like how can OI practices enhance sustainable production.

The decision to use this research design stems from the two objectives of this study, firstly, to contribute to theoretical understanding of OI and sustainability, and secondly, to identify practical insights for SMEs in the manufacturing sector. This ensures that the findings are both academically rigorous and practically relevant.

### 3.1. Case Selection

The case selection was guided by purposive sampling, aiming to identify firms that embody the central themes of this study, environmental sustainability and OI within the manufacturing context. Specifically, the cases were selected from among SMEs operating in the Portuguese manufacturing sector, with a clear orientation toward sustainability and demonstrated engagement in collaborative innovation practices. This strategic and theoretically informed

choice aligns with prior empirical studies utilizing case-based methodologies in similar domains, thereby ensuring methodological coherence. The criteria used were: (i) the organization must qualify as an SME under the European Commission's definition (2015); (ii) it must be embedded in manufacturing activities, with a preference for those within medium or low-technology sectors; and (iii) it must exhibit active participation in external innovation collaborations explicitly oriented toward environmental or sustainability objectives. The firms selected met all criteria and provided a suitable empirical context for exploring the intersection of OI and environmental sustainability in production.

Figure 1- Step by step process for the selection of companies

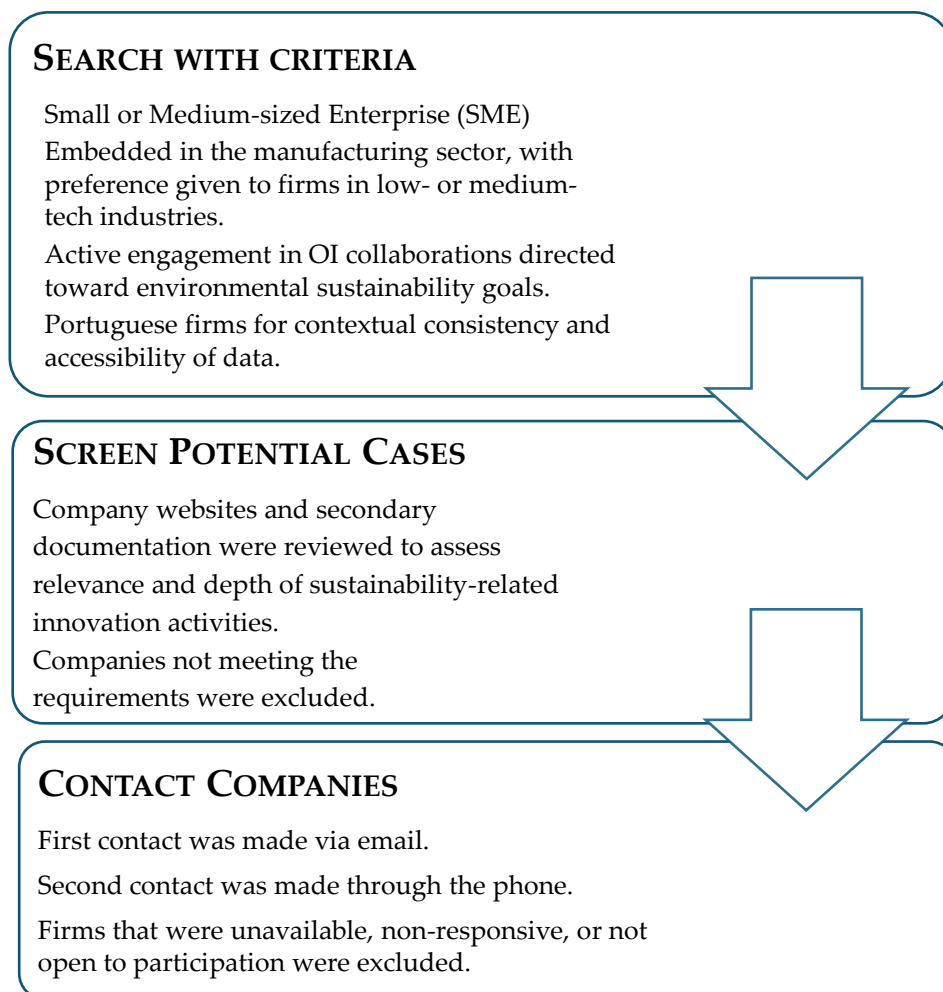


Table 2 - Overview of Managers' Information

	Manager A	Manager B	Manager C	Manager D
Age (years)	57	61	54	50
Gender	Male	Female	Male	Male
Highest Academic Level Achieve	Doctorate	Bachelor's degree	Bachelor's Degree	Bachelor's Degree
Experience in manufacturing industry (years)	20	40	14	20
SOI Awareness (High/Medium/Low)	High	Medium	Medium	High
Identified Dynamic Capabilities	Absorbative Capacity; Innovation Reconfiguration; Stakeholder Collaboration; Learning Orientation	Collaborative Capabilities; Adaptive Capability; Experiential Learning	Innovative Reconfiguration; Absorbative Capacity; Inter-rationality	Infrastructure Building; Strategic Foresight; Stakeholder Coordination

Table 3 - Overview of Companies' Information

	Company A	Company B	Company C	Company D
Year of Inception	2003	2000	2001	1986
Ownership	Ltd	Ltd	Ltd	Ldt
Industry	Pellet Manufacturing	Glass Pane Transformation	Footwear Production	Textile Production
Number of Employees	34 (11 for the pellets manufacturing activity)	38	47	20
Stakeholders / Knowledge Intermediaries	Business Partnerships; Suppliers; Clients; Industry Fairs; Universities; Research Centres; Innovation Cluster; Governmental Institutions	Business Partnerships; Suppliers; Clients;	Business Partnerships; Suppliers; Clients; Industry Fairs;	Business Partnerships; Suppliers; Clients; Industry Fairs; Competitors;
Sustainable Certifications	3*	3*	3	2
SOI Initiatives	3	2	4	3

## 3.2. Data Collection

To conduct this research, semi-structured interviews were employed as the primary data collection method. This technique was selected due to its flexibility and capacity to facilitate in-depth discussions around key themes, while simultaneously allowing for the emergence of new insights during the conversations. The semi-structured format enables the interviewer to follow a previously defined guide composed of open-ended questions, yet remains responsive to unanticipated developments in the dialogue, creating a conversational dynamic rather than a rigid question-and-answer structure.

The interviews were conducted with four senior managers and decision-makers within the selected manufacturing SME, as they are individuals directly involved in strategic planning, sustainability efforts, and external innovation collaborations. The interviews were carried out between October 2024 and March 2025 and lasted between 20 and 60 minutes each. Each session was recorded, transcribed, and initially coded on the same day to preserve contextual nuances and ensure accurate interpretation of content.

Consistent with the recommendations of Magnani & Gioia (2023), a rigorous approach was adopted in capturing first-hand accounts of how OI is applied to advance environmental sustainability in production settings. This aligns with the broader objective of theory-building through inductive analysis, where the voices of participants play a central role in constructing emergent concepts.

Additionally, triangulation was employed to enhance the reliability and depth of the findings. Supplementary information was gathered from the company's website and from publicly available databases, which provided

contextual background on the firm's history, innovation activities, environmental certifications, and collaborative networks.

This multi-source approach adheres to qualitative research best practices by capturing rich, multifaceted data, and reinforces the study's contribution to both theoretical inquiry and practical understanding of SOI in the manufacturing sector.

### 3.3. Data analysis

This study followed an abductive approach to data analysis, which allowed for a continuous back-and-forth between what was observed in the field and the theories used to interpret it. This method was particularly useful given the complexity of the topic, how OI contributes to environmental sustainability practices in manufacturing, because it made it possible to refine theoretical ideas as insights emerged from the data. The goal was not only to understand how OI practices played out in the case companies, but also to uncover the underlying mechanisms that shape sustainable innovation through OI.

To analyze the data collected from the semi-structured interviews, the study applied grounded theory principles. This approach is well-suited for research that doesn't start with fixed hypotheses and instead builds theory from the ground up (Magnani & Gioia, 2023). Grounded theory provides a structured yet adaptable framework for analyzing qualitative data, helping to identify patterns and themes directly from what participants shared.

The analysis followed a three-step process based on the Gioia methodology (Magnani & Gioia, 2023). The first step, known as unitizing, involved reading the interview transcripts multiple times to become deeply familiar with the content. During this stage, meaningful excerpts, referred to as "thought units", were identified. These were usually sentences or short groups of sentences that

expressed a clear idea related to sustainability or OI practices, such as motivations for collaboration, innovation strategies, or learning processes.

In the second step, these thought units were grouped into broader themes, called second-order categories. These categories represented more general ideas like integrating outside knowledge, building trust in partnerships, or finding new ways to solve problems collaboratively. Importantly, these themes were derived from the data itself rather than being imposed from existing theory.

In the final step, once the key themes had been fully developed, they were combined into even higher-level concepts known as aggregate dimensions. These dimensions reflected the larger patterns that addressed the core research question, such as the role of dynamic capabilities in sustainable innovation, how knowledge flows through OI, or how sustainability goals are embedded in institutions' strategies. This process resulted in a structured framework that connected the raw data to broader theoretical insights.

In line with Magnani & Gioia (2023), the goal of building this data structure was not just to describe what was happening in these firms, but to explain how and why OI supports sustainability in production. By grounding the analysis in the real experiences of the participants, the study ensured that its theoretical contributions remained relevant and credible.

Table 4 - Data Structure

<b>1st-Order Concepts (Quotes)</b>	<b>2nd-Order Themes</b>	<b>Aggregate Dimension</b>
Statements that mention the emphasis on adoption of eco-friendly production as a strategic stance.	Environmental Orientation & Green Solutions	Sustainability as Strategic Orientation
Statements mentioning the leveraging of waste from other industries to reduce environmental impact		
Statements showing that institutional norms and client preferences shape eco-innovation.	Regulatory & Client-Driven Sustainability Demands	
Statements that mention that firms acquire external ideas, tech, or expertise to drive eco-innovation	Sustainable Inbound Innovation	Knowledge Flows in SOI
Statements showing firms ability to share internal solutions, insights, or processes with external players.	Sustainable Outbound Innovation	
Statements mentioning mutual co-creation with suppliers, customers, or industry peers.	Sustainable Coupled Innovation	
Statements mentioning dynamic capabilities building for sustainability purposes.	Dynamic Capabilities	SOI Capability Building
Statements identifying suppliers, associations, agencies as crucial enablers.	Knowledge Intermediaries	Stakeholder Involvement in SOI
Statements showing the development of more eco-friendly product lines and brand extensions.	Green New Product Development	SOI Outcomes
Statements showing that partners jointly design or refine sustainability offerings.	Value Co-Creation with External Collaborators	
Statements proving that sustainability fosters credibility and new markets.	Enhanced Brand Legitimacy & Market Expansion	
Statements showing specialized and nonspecialized human capital deficits.	Resource Constraints & Skilled Labor Shortage	SOI Implementaion Constraints
Statements mentioning unstable demand and late payments.	Market Volatility & Financial Uncertainty	
Statements showing the concerns in sharing internal expertise.	Concerns Over Knowledge Spillovers	

## 4. Findings / Results

### 4.1. Sustainability as Strategic Orientation

Following an analysis of all four manufacturing firms interviewed, sustainability emerges not as a reactive compliance activity but as a strategic orientation embedded from the inception or early development of the firms.

#### 4.1.1. Environmental Orientation and Green Solutions

In all cases, environmental concerns were central to the companies' identities and value propositions. For Company A, the motivation emerged from an urgent environmental concern, after the forest fires in Portugal in 2003. The founder started seeking innovative solutions for forest management and ended up creating a bioenergy cluster, that rests on the valorization of sawmill waste. He emphasizes that "the pellet is something to valorize subproducts or residues, not to chop down trees to make pellets," underscoring a clear rejection of unsustainable biomass practices.

Similarly, Company D integrated environmental values by reviving traditional techniques using organic raw materials. The manager exhibited sustainability guided decisions, reflecting an integrated strategic approach rather than isolated initiatives: "we wanted to create a brand that was completely different, sustainable in all its components, from materials to logistics."

Companies B and C, while more conventional, gradually incorporated environmental goals as strategic differentiators. Company C, for example, introduced biodegradable soles and started measuring the environmental impact of their production processes. According to manager C, "it wasn't just because the market asked for it, it's because we really believe we need to reduce our

environmental footprint.” Manager B even stated that “I think sustainability is a way of life, not just about business”. These companies exemplify a proactive stance toward environmental responsibility, motivated by internal convictions and long-term competitiveness.

#### 4.1.2. Regulatory and Client-Driven Sustainability Demands

All four companies described external pressures as influential forces in shaping their sustainability trajectories. Regulations and evolving consumer expectations were commonly cited as accelerators. Manager B emphasized how European standards pushed them to invest in cleaner technologies. As the manager stated, “today we cannot afford not to have certain certifications. Clients expect that, and regulators demand it.”

Likewise, Company C noted the role of international buyers in pressuring them to meet sustainability benchmarks. The more demanding Northern Europe markets lead Company C to adopt stricter environmental controls and traceability systems. In contrast, Company D highlighted local market inertia, suggesting that while their ecological brand identity attracted niche consumers, widespread adoption was still limited by cultural and economic constraints.

Overall, these findings demonstrate how both institutional and market dynamics create a “double pressure” system that complements firms' internal motivations. While regulations and client preferences act as external triggers, the depth and authenticity of sustainability adoption are clearly tied to leadership beliefs and strategic choices.

## 4.2. Knowledge Flows in SOI

A defining trait of SOI practices across all four firms was their active engagement in knowledge flows that transcend organizational boundaries. This aggregate dimension comprises three core second-order themes: Sustainable Inbound Innovation, Sustainable Outbound Innovation, and Sustainable Coupled Innovation.

### 4.2.1. Sustainable Inbound Innovation

All participating companies emphasized the value of acquiring external knowledge as a key component of their sustainability strategies. Company A leveraged international study visits and extensive technical research. As the manager A stated, “I did not invent anything, I saw it was already being done abroad and adapted it to our ecosystem.” Company C similarly sourced external insights from international clients. Their innovation team actively monitors trends and technologies, exemplifying a structured absorptive approach to sustainable knowledge intake.

In Company D, sustainability-oriented design is influenced by studying circular ecosystems, participating in industry seminars, collaborating with academic experts and heritage centres. This shows a deliberate strategy of importing niche knowledge to inform local practices.

### 4.2.2. Sustainable Outbound Innovation

Outbound flows of knowledge, where firms share their innovations externally, were evident in how companies sought to influence peers, clients, and even regulators. Company A has consistently shared operational practices and technical data with smaller pellet producers, reinforcing a sector-wide shift

toward cleaner bioenergy. According to manager A, “we are often consulted because of the efficiency of our system, and we help others replicate it.”.

Company B licenses aspects of its process to subcontractors and shares environmental performance data with partners to foster more transparent supply chains.

Company D engages the public in co-education through transparency campaigns about materials, impacts, and certifications. Manager C also stated that “We shared ideas with our suppliers and other shoe producers... even suggested materials like recycled rubber without asking anything in return.”, reinforcing the use of sustainable outbound flows of knowledge. Their approach blurs the lines between innovation and activism, as they aim to elevate environmental literacy across their client base and the broader fashion ecosystem.

### 4.2.3. Sustainable Coupled Innovation

Coupled innovation was prominently observed in cross-sector partnerships. Company B collaborates with equipment manufacturers to co-develop more energy-efficient machinery, influencing both upstream technology and downstream sustainability impact. Meanwhile, Company C has launched joint product lines with European collaborators, merging aesthetics with biodegradability, highlighting a creative form of co-development.

For Company D, partnerships with artisans, producers, and packaging cooperatives have been essential, supporting both operations and its sustainability mindset. The manager noted: “We don’t do sustainability alone,” and “Our suppliers are part of our story.”

Company A, while more technologically focused, participated in a now-concluded national cluster initiative that brought together producers, researchers, and government agencies to share knowledge and build collective

capabilities. Though this initiative was discontinued, the firm continues to apply the co-created knowledge in its operations.

In all cases, strategically managed knowledge flows optimized both environmental performance and innovation effectiveness. Inbound flows provided access to advanced practices and sustainability expertise; outbound flows enabled sector-wide influence; and coupled innovation drove collaborative problem-solving. This triangulation was a crucial mechanism for sustainable transitions in manufacturing.

## 4.3. Capability Building

The ability of firms to engage in SOI depends significantly on their internal capacities to absorb, adapt, and operationalize knowledge related to sustainability. This aggregate dimension is informed by the second-order theme Dynamic Capabilities, encompassing the organizational routines and strategic behaviors developed to navigate and integrate sustainability into core processes.

### 4.3.1. Dynamic Capabilities

All firms implemented adaptive, learning-based approaches to support sustainability innovation. Company A locally adapted production through internal skill development and trial and error adjustments to fit regional conditions. As noted by the founder, “We had to experiment and adjust the equipment to our specific forest conditions. It was trial and error process.”

Similarly, Company B developed internal absorption and technical capabilities to create a custom system, integrating environmental criteria into its engineering and operations. The manager emphasized: “It took time, but we invested in training and slowly built a system that works not just for today but for future standards too.”

Company C focused capability building on design and branding by tracking environmental indicators, training designers in eco-friendly materials, and ensuring supplier traceability. Manager C noted, “We didn’t have this culture before. We had to bring in consultants, run workshops, and slowly change how people think about the product.”

Company D underwent a major transformation, transitioning from conventional manufacturing to a circular, sustainability-oriented business model, developing capabilities in supply chain auditing, low-impact techniques, and lifecycle analysis. As manager D stated: “We brought in people with a completely different mindset... it wasn't just about skills, it was about creating a culture.”

In all companies, the development of dynamic capabilities was not instantaneous but evolved through experiential learning, failure, and iteration. These capabilities included sensing environmental opportunities, seizing collaboration channels, and transforming internal routines and culture.

Company B highlighted the role of their quality manager in integrating sustainability KPIs across departments, while Company C’s marketing team co-led sustainability audits to ensure alignment between brand promise and operational reality.

Capability building extended beyond technical skills to include softer dimensions such as cross-functional coordination, strategic foresight, and leadership. Examples from Companies B and C show how roles across departments contributed to embedding sustainability.

Overall, dynamic capabilities are essential for effective SOI, allowing firms to internalize external sustainability knowledge and reshape their identity, processes, and offerings around it. Especially in SMEs environments, these capabilities often emerge organically, fueled by necessity, experimentation, and stakeholder dialogue, rather than through formal R&D infrastructures.

## 4.4. Stakeholder Involvement in SOI

The success of SOI practices in the participating firms was consistently tied to the proactive involvement of external stakeholders. This aggregate dimension is represented through the second-order theme Knowledge Intermediaries, which captures the range of actors that enabled and accelerated the firms' sustainability agendas.

### 4.4.1. Knowledge Intermediaries

All four firms collaborated with key stakeholders to advance sustainable innovation. Company A notably partnered with an innovation cluster and government bodies, fostering trust-based relationships with municipalities, research institutes, and regulatory bodies that enabled its early shift to clean energy. The company manager stated that "we formed a cluster because we understood that we couldn't do this transition alone." that collectively facilitated the firm's early adoption of clean energy practices. Universities and research centres were key intermediaries, providing expertise, legitimacy, and credibility to support firms' sustainable innovation efforts.

Company B's transition to more sustainable processing was enabled by suppliers and technical partners. Manager B remarked: "we didn't invent the technology, but we had partners who did and they helped us adapt it." Industry fairs and certification bodies were also mentioned as essential sources of up-to-date environmental requirements and benchmarking practices.

In Company C, client demands often acted as the trigger for sustainability improvements, but partnerships with consultants, materials suppliers, and retailers allowed the company to meet these challenges. The firm's manager highlighted: "we rely on our suppliers to guide us on what's new and more sustainable. We're in constant dialogue."

Company D's stakeholder network is community-based and values-driven, involving artisans cooperatives, packaging manufacturers, and sustainability advocates who co-design eco-friendly solutions. Their model emphasizes trust, social purpose, and cultural alignment, as stated: "our intermediaries are not just technical, they share our values. That matters to us."

These institutions helped firms access knowledge, reduce risk, and align with sustainability norms. In SMEs with limited R&D capacity, these relationships were proven central to the innovation process.

## 4.5. SOI Outcomes

All of the interviewed firms achieved tangible and strategic outcomes from SOI, captured under three interrelated second-order themes: Green New Product Development, Value Co-Creation with External Collaborators and Enhanced Brand Legitimacy & Market Expansion.

### 4.5.1. Green New Product Development

Green product innovation was a key outcome of SOI. Company A launched premium wood pellets by revalorizing sawmill waste. The innovation was not just environmental but also product-based, emphasizing both environmental benefits and a sustainability message. "We don't just sell heat, we sell a product with a sustainability message," stated the manager.

Company C demonstrated product innovation with eco-friendly footwear, incorporating biodegradable soles and low-impact materials. "Each season we push to increase the percentage of sustainable components. Our R&D is now fully focused on reducing impact," said the manager.

Company D's textile brand built its entire offering on eco-conscious design, producing limited-run collections with organic dyes and biodegradable

packaging, embodying sustainability in aesthetics, materials and lifecycle under the concept of "fashion with responsibility."

#### 4.5.2. Value Co-Creation with External Collaborations

SOI fosters collaborative innovation with firms co-developing sustainability solutions with clients, suppliers, and even competitors. Company B worked with equipment vendors on energy-efficient machines. "We gave feedback on prototypes. In a way, we helped design the system," explained their manager.

Meanwhile, Company D partnered with suppliers and craftspeople to create recyclable tags using agricultural waste. "We needed their knowledge, and they needed our vision," the manager stated, emphasizing the mutual learning dynamic.

Company C collaborated with international clients to co-designed eco-friendly shoes based on specific environmental certifications requested by foreign retailers, strengthening their portfolio and relationships with strategic buyers.

#### 4.5.3. Enhanced Brand Legitimacy and Market Expansion

Engaging in SOI brought reputational and market benefits, improving brand image and opening new customer segments to all firms.

For Company A, "having a sustainability focus gave us early legitimacy with municipalities and regulators," facilitating contract access. Similarly, Company D attracted a niche, loyalty-driven clientele willing to pay a premium for transparent, environmentally ethical fashion. "We became more than a clothing brand. We became a statement," the manager noted. Even Company B,

whose industry is traditionally less visible to end consumers, saw reputational gains in B2B markets.

Overall, SOI outcomes created new value configurations, enabled by external collaboration and shaped by sustainability goals. These outcomes highlight the strategic value of sustainability-focused OI for manufacturing SMEs.

## 4.6. SOI Implementation Constraints

While all four companies demonstrated commitment and progress toward SOI, they also faced significant constraints. These challenges fall under three second-order themes: Resource Constraints & Skilled Labor Shortage, Market Volatility & Financial Uncertainty, and Concerns Over Knowledge Spillovers.

### 4.6.1. Resource Constraints and Skilled Labor Shortage

Human capital limitations, especially in manufacturing expertise, were a key barrier. Company A faced challenges in finding trained professionals, which slowed innovation efforts: “We had to train everyone ourselves. There’s no one graduating with knowledge in this field.” Similarly, Company C struggled to recruit staff with both sustainability knowledge and industry experience, making recruitment and training a significant investment: “It’s hard to find people who understand both sustainability and fashion in manufacturing.”

Company D struggled to maintain artisanal production while scaling, as skilled workers with an understanding of their ecological processes were hard to find, delaying product launches: “We don’t just need regular seamstresses, we need ones who understand and believe in our ecological process”. These

challenges were found to be worsened by the limited resources of SMEs, making it difficult to attract or develop specialized talent in sustainability and innovation management.

#### 4.6.2. Market Volatility and Financial Uncertainty

Financial instability and fluctuating demand were cited as constant sources of tension. Company B discussed how uncertainty impacted their processing business: “Projects get canceled or postponed. That throws off our investment in innovation”.

For Company C, the export-oriented nature of their business exposed them to foreign currency risks and changing buyer behaviours. “Sometimes we invest in eco products, and the client changes specs last minute or delays orders,” said the manager.

Company D emphasized that sustainable production comes with higher upfront costs, which can be difficult to absorb when facing inconsistent demand. “We’re always at risk of having our values priced out by cheaper, unsustainable competitors,” said the founder.

Even Company A, which had long-term public contracts, noted that regulatory frameworks were shifting and could jeopardize previously stable revenue streams. Market volatility and financial uncertainty, acted as a structural risk undermining long-term planning in most cases.

#### 4.6.3. Concerns Over Knowledge Spillovers

Despite a general openness to collaboration from all the interviewed managers, some firms expressed caution when it came to sharing internal knowledge. Company B was particularly protective: “We share data to some extent, but not everything. There’s a line between collaboration and giving away our edge.”

Company C expressed concerns about potential imitation, fearing that revealing their sustainability process could allow larger competitors to replicate it more quickly and cheaply “If we reveal our entire sustainability process, what prevents a larger competitor from doing it faster and cheaper?” These highlight a tension in SOI practices: balancing value co-creation with the risk of appropriation. Although cautious about core innovations, manager C noted that “sharing basic standards helps raise the bar and doesn’t harm us competitively,” acknowledging the strategic diffusion of sustainability practices.

Company D navigated this constraint by maintaining transparency with consumers but controlling access to core process details with commercial partners. They emphasized relational trust and selective disclosure as strategies to mitigate knowledge spillovers. These limitations in labor, capital, demand, and intellectual property, form the practical boundaries within which SOI must operate, emphasizing the need for supportive ecosystems, policy interventions, and long-term strategic alignment beyond individual firm efforts.

## 5. Discussion

Environmental sustainability of manufacturing practices can be greatly influenced by external institutional pressures, supported by intermediary networks, driven hybrid innovation strategies, and limited by systemic; (Fernández et al., 2021; (Obradović et al., 2021); Caloffi et al., 2023)

The findings reveal that firms are influenced simultaneously by regulatory requirements and market expectations regarding environmental responsibility. This dual influence acts as a strategic forcing mechanism, motivating firms to pursue sustainability through OI.

This confirms findings of Fernández et al. (2021), who conceptualize a double-pressure system combining top-down regulations and bottom-up stakeholder demands as a catalyst for environmental innovation. Firms perceive sustainability not as optional, but as a strategic necessity to remain viable and legitimate in evolving markets. Similarly, Radnejad et al. (2017) and Obradović et al. (2021) argue that institutional and stakeholder demands shape firms' sustainability agendas and encourage the adoption of open, collaborative innovation models.

This convergence of institutional and market logic creates a fertile ground for OI to emerge as both a compliance strategy and a market differentiation tool, evidently displayed in the findings and thus creating the following first proposition:

***Proposition 1: Firms facing both regulatory and client pressures are more likely to adopt SOI practices to meet institutional demands and enhance their market position.***

Firms consistently leverage external knowledge intermediaries, such as trade associations, research centres, public agencies, and certification entities, to

bridge internal capability gaps. These intermediaries enabled firms to access technical expertise, funding programs, and evolving sustainability standards.

This aligns with Chesbrough & Crowther (2006), who proposed that OI depends on effective knowledge flows across organizational boundaries. Caloffi et al. (2023) further emphasized the role of public intermediaries and local governance in building firm-level absorptive capacities for sustainability. These actors reduce barriers for SMEs by translating complex policies, diffusing innovations, and coordinating networks that promote sustainable industrial practices. In practice, firms with higher reliance on intermediaries demonstrated a greater ability to anticipate changes, meet environmental requirements, and participate in collaborative initiatives, which leads to the following:

***Proposition 2: Firms that engage with diverse knowledge intermediaries are better positioned to absorb sustainability knowledge and implement effective SOI strategies.***

Most firms adopted complementary forms of OI, blending inbound, outbound, and coupled innovation approaches, rather than relying on a single model. This hybridization allowed them to adapt to context-specific challenges while managing risks related to openness.

Inbound innovation typically involved the acquisition of eco-friendly technologies or sustainable inputs. Outbound practices included sharing internal know-how or practices to align partners or clients. Coupled innovation involved co-developing sustainable solutions with suppliers, public institutions, research centres, NGOs, or other business partners.

Chesbrough & Crowther (2006) and Slotegraaf (2012) noted that hybrid OI models enable faster adaptation and reduce the limitations of internal R&D. Watanabe et al. (2011) observed that innovation often unfolds during the diffusion and application phases, which hybrid strategies support through iterative feedback and shared learning.

All the firms in this study demonstrated a practical balance between openness and control, maximizing collaboration while safeguarding their core assets, leading to the following:

***Proposition 3: Hybrid SOI strategies enhance firms' agility and value co-creation in addressing varied sustainability challenges.***

Along with the environmental impact improvements, firms indicated that the integration of SOI enhanced their brand legitimacy, supply chain attractiveness, and international competitiveness. By actively promoting sustainability, firms improved their visibility and credibility, gaining access to markets with rigorous environmental standards.

This supports the arguments of Radnejad et al. (2017) and Watson et al. (2018), who demonstrate that SOI contributes to both environmental legitimacy and commercial expansion. Sustainability certification and traceability systems, often co-developed or diffused through OI networks, enhanced client trust and facilitated new partnerships.

Therefore, firms that embedded sustainability into their innovation narratives positioned themselves more clearly in increasingly segmented global markets, where buyers prioritize environmental credentials: revealing the following:

***Proposition 4: Firms that strategically align their SOI practices with sustainability narratives and supply chain expectations are more likely to achieve reputational legitimacy and enter environmentally sensitive markets.***

Despite the multiple perceived benefits of SOI, firms reported ongoing implementation barriers, most prominent among them were labor shortages, financial volatility, and concerns about knowledge leakage. These constraints are particularly acute for SMEs that operate under tight margins or limited internal capacity.

Farjam et al. (2023) identify skilled labor deficits as a core bottleneck in sustainability-oriented innovation, especially in traditional sectors. Purdy et al. (2023) further discuss how market volatility and delayed returns on green investments deter SMEs from fully committing to SOI, despite strategic interest.

Moreover, the openness inherent to OI was seen by some firms as a competitive threat, reinforcing a cautious approach to external collaboration. This aligns with Yun et al. (2022), who argue that while OI can accelerate sustainability transitions, it also amplifies risks, particularly for firms with fragile IP positions or weak bargaining power.

Firms mitigated these risks through trust-based collaborations and selective disclosure. However, these workarounds suggest a need for better-designed ecosystems that support openness while preserving strategic security. Therefore, It leads to the following:

***Proposition 5:***

***The effective implementation of SOI depends on a firm's ability to manage structural constraints through ecosystem support and strategic control of knowledge flows.***

Based on the patterns identified through the data structure and aggregate dimensions, it becomes evident that no single OI practice is used in isolation. Instead, the effectiveness of SOI comes from how firms combine different approaches, such as inbound knowledge acquisition, collaboration with intermediaries, and shared development with partners. These practices are shaped by external pressures, internal resources, and the surrounding innovation ecosystem. The conceptual framework presented illustrates this interaction, showing how regulatory demands, knowledge networks, and strategic choices come together to support environmentally sustainable goals. Offering a visual summary of how firms put SOI into practice under different conditions.

## 6. Conclusion

This study examined the role of OI in enhancing the environmental sustainability of production processes, focusing on SMEs within the Portuguese manufacturing sector. The results show that SOI acts not only as a tool for innovation but also as a strategic response to growing environmental and institutional pressures. Firms embraced sustainability both because they valued it internally and because they faced demands from clients, regulators, and wider society. This combination of internal motivation and external expectation reflects what Fernández et al. (2021) describe as a “double pressure system,” where companies align their operations with both values and market realities.

Companies notably used all three types of OI to advance sustainability practices. Inbound innovation helped them access external knowledge and technologies, while outbound innovation allowed them to share their sustainable practices and solutions with others. Coupled innovation, based on partnerships and joint ventures, enabled more complex forms of collaboration that proved crucial in addressing systemic environmental challenges.

The ability to absorb new knowledge, learn as an organization, and effectively engage with stakeholders were identified as the key dynamic capabilities supporting these innovation efforts. These capabilities allowed firms to adapt external sustainability insights to their internal processes and vice-versa. In addition, knowledge intermediaries like universities, industry clusters, and certification bodies played an important role, helping companies access resources, build legitimacy, and apply sustainability standards effectively.

Despite their efforts, the firms faced several barriers. These included limited access to financial and human resources, fears about intellectual property leakage, and challenges in aligning goals with external partners. The risks of

opening up were significant, particularly in SMEs, and had to be managed carefully to ensure long-term benefit.

The findings support that firms with a clear sustainability strategy, strong partnerships, diverse innovation models, and well-developed internal capabilities are better equipped to implement SOI successfully and to benefit from it reputationally and commercially.

This study contributes to the growing literature at the intersection of OI and sustainability by showing how manufacturing SMEs can embed sustainability in their innovation practices. It demonstrates how firms are not just complying with regulations but actively using OI to create environmental value and competitive advantage. For managers and policymakers, the findings offer practical insights into how collaborative innovation can drive sustainable change.

When interpreting the results of this dissertation, specific aspects might limit the conclusions that were inferred. Firstly, it is based on a small sample of four Portuguese SMEs, which limits the extent to which the findings can be generalized. Next, the primary data came from interviews, which can be subjective. Although supplemented with secondary data, future studies could use quantitative or longitudinal methods to strengthen the robustness of the conclusions. Additionally, the focus was mainly on environmental sustainability. The social and economic aspects were only briefly touched upon, leaving space for a more balanced approach in future research to provide a fuller understanding of SOI. Finally, the study was conducted during a post-pandemic period. The responses and strategies observed may reflect short-term adaptations rather than permanent strategic shifts.

Future research on SOI could benefit from several promising directions. Comparative studies across countries or industries could uncover how different contextual factors influence the adoption and effectiveness of SOI practices. Investigating the role of public policy frameworks and innovation ecosystems may also shed light on the institutional enablers or barriers that firms encounter.

In parallel, exploring the integration of digital technologies such as artificial intelligence, blockchain, or digital twins with sustainability-oriented innovation strategies offers a valuable avenue, as these tools may both facilitate and complicate implementation. Further attention should also be directed toward the micro-foundations of dynamic capabilities, including leadership styles, organizational routines, and workplace culture, which play a critical role in shaping a firm's ability to innovate sustainably. Lastly, the development of more comprehensive evaluation metrics, beyond environmental outcomes, to include resilience, inclusiveness, and long-term competitiveness would enhance our understanding of SOI's broader value and practical impact.



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# Appendix

## **Questionnaire:**

The questionnaire, which is in front of you, does not pose any test of knowledge nor aptitude test. There is no right or wrong or worthy and less worthy response. All answers are good if you express your true opinion. The findings will be used solely for scientific research purposes, to prepare the master work of student Afonso Esteves da Silva Reis. The questionnaire is anonymous and confidential.

1. Gender:
2. Age:
3. Highest academic level:
4. Years of experience in the manufacturing industry?
5. Sustainable open innovation awareness?
6. What are the different types of dynamic capabilities?
7. What is the year of inception of the company?
8. What is the type of Ownership of the company?
9. What is the main industry type of the company?
10. What is the current number of employees?
11. What are the different types of knowledge intermediaries of the company?
12. What is the number of sustainable certifications of the company?
13. What are the open innovation initiatives for sustainable production?
14. What is the story of the company?
15. What is the genesis of sustainability and open innovation practices?
16. What is the overall impact of sustainable open innovation practices in manufacturing?
17. What are some of the standing constraints that the company faces in the implementation of the sustainable open innovation practices?

Table 5 - Aggregate dimensions, 2nd Order Themes and 1st Order Thought Units of Sustainable Open Innovation practices in manufacturing

Aggregate Dimension	2nd-Order Themes	1st-Order Thought Units	
		Manager	Quotes
Sustainability as Strategic Orientation	Environmental Orientation & Green Solutions	A	<p>"We started with the logic that pellets should primarily be used to valorize by-products or residues, not to crush entire trees, which unfortunately happens nowadays in some places."</p> <p>"Our pellet is very ecological. Basically, we only transport sawdust from sawmills here, and the energy used to produce the pellet is less than 10% of its energy content."</p>
		B	<p>"Glass is one of the few materials that doesn't pollute and lasts forever... It's a natural product that's been used since ancient Egypt. I think sustainability is a way of life, not just about business."</p> <p>"We don't allow any glass from China into our factory because we know their production processes and they don't meet our standards."</p> <p>"We invested in a €300,000 machine to eliminate dangerous edges from the glass. Now, the product is safer and complies with EU standards, that's product innovation."</p>
		C	<p>"About 14 years ago, we began working with sustainable products. Starting with biodegradable shoes, then vegan, and now primarily recycled or a mix of both."</p> <p>"Today, 50% of the energy we consume annually is produced on-site from solar panels. The rest is purchased as green energy."</p> <p>"We replaced our highest-consumption machinery, the ovens, with new, much more efficient ones. One of them cut consumption by 80%."</p>
		D	<p>"We don't claim to be sustainable just by using organic yarn. We look at the entire supply chain. For instance, we reuse all kinds of materials and even make storage bags from fabric waste."</p> <p>"It was a decision I had been considering for a while... clients suggested we had to move in that sustainable direction."</p> <p>"Since 2016 we certified with STeP by OEKO-TEX, focused on sustainability, and progressively integrated sustainable materials, efficient production practices, and waste reduction into our operations."</p> <p>"We reuse everything possible here. Old cutting tables,</p>

		leftover fabric, even computers—we buy reconditioned ones. It's a company-wide mindset."
Regulatory & Client-Driven Sustainability Demands	<b>A</b>	<p>"There was an open call from the innovation agency for the creation of new clusters in Portugal. We submitted a proposal to create a bioenergy cluster to gather and promote information for investment in this area."</p> <p>"What I found is that in other countries, they were already collecting and processing wood and biomass to produce heat."</p> <p>"The consumer has the power. If they are informed and aware, they can choose responsibly. That's why it's so important to differentiate our product."</p>
	<b>B</b>	"We are certified under ISO 9001:2015, and also under norm 1279 for double-glazed glass manufacturing. We also comply with CE marking, which is mandatory in Europe." "I want to certify our environmental performance soon, but that's tough because it's not fully regulated or enforced yet. Still, it's part of our goal."
	<b>C</b>	<p>"The shift came not only from internal motivation but also from market demand, especially in the vegan product segment."</p> <p>"It was a decision I had been considering for a while... clients suggested we had to move in that sustainable direction."</p> <p>"We sought out certifications that reflect how the market sees us. For example, the GRS (Global Recycled Standard), which tracks product content and social compliance."</p> <p>"We're starting SMETA certification due to client requirements, even though its social aspects overlap with the GRS."</p>
	<b>D</b>	<p>"We only started receiving real orders linked to GOTS certification about a year ago. Until then, the certification added image value but didn't generate real market demand."</p> <p>"International tenders and clients, especially German, Swiss, and Nordics, increasingly require certified environmental and ethical practices."</p> <p>"When we started exporting, especially to Germany, we learned a lot about sustainability standards and best practices, that knowledge shaped our strategy."</p>

Knowledge Flows in SOI	Sustainable Inbound Innovation	A	<p>"We began with international visits and research. We visited several centers abroad and identified pellets as a promising technology. I didn't invent anything. I discovered that in other countries they were already collecting and processing biomass for heat production."</p> <p>"The upgrades in our equipment, like increasing the drying and cooling capacity, were based on insights and best practices observed during the early research phase."</p> <p>"The idea came to me while researching biomass energy... I'm an engineer, and through this process, we adapted global practices to our own context."</p>
		B	<p>"We upgraded from a manual gas injector to an automatic one, which ensures better quality and allows us to guarantee the gas insulation in our double-glazed units for ten years."</p> <p>"We work with Guardian Select, part of an American group, and they send us a lot of technical information... that's where we get informed."</p>
		C	<p>"We went abroad to learn how to develop sustainable products. We chose Germany, the best place at the time, and found a very open, knowledge-sharing society."</p> <p>"That's how we got access to many concepts that still guide our sustainable design today."</p>
		D	<p>"Many innovations came from talking to clients and suppliers during international fairs. Some vendors even share experimental fabrics, and we make a few sample garments in return."</p> <p>"Participation in international fairs helped us identify sustainable trends, materials, and technological advances we later adopted."</p>
	Sustainable Outbound Innovation	A	<p>"We held a seminar for pellet distributors during our 15th anniversary where I explained combustion theory and pellet-burning problems... This knowledge helped the market understand that many issues weren't caused by the pellet itself." "I even helped some of our competitors with this knowledge. This is an example of open innovation, sharing information to develop the market itself."</p>
		B	<p>"We issue certificates to our clients so they know exactly what type of glass they're receiving. This transparency helps them make informed decisions, we help educate the market."</p> <p>"We even show clients our product composition and tell them: 'Ask your contractor what glass they're using.' That gives consumers the tools to choose quality, it's how we raise awareness."</p>

		<p><b>C</b></p>	<p>"We encouraged a sole manufacturer to incorporate tire granulate from a nearby recycler into their production. We prototyped the product and shared it without expecting exclusivity." "Some clients who knew us for recycling began suggesting product adaptations. We tested them and these clients later used the adaptations with other producers too."</p>
		<p><b>D</b></p>	<p>"We encourage clients to use leftovers for capsule collections, promoting sustainability and waste reduction." "When clients request environmentally harmful techniques, like plastisol printing, we propose more sustainable alternatives."</p>
	<p>Sustainable Coupled Innovation</p>	<p><b>A</b></p>	<p>"We work in a value chain, we add value to the pinewood supply chain, working with sawmills and using their by-products. It's a cooperative effort that supports the entire ecosystem." "I've spoken with some people already researching ways to certify our value chain... The idea is to create a certification seal in Portugal to highlight sustainable practices versus imported pellets made from deforestation."</p>
		<p><b>B</b></p>	<p>"We depend heavily on the training and awareness of builders and architects... If they're not informed about energy-efficient glass, we all lose. So we help them as they help us. It's a joint effort to raise the bar."</p>
		<p><b>C</b></p>	<p>"We constantly exchange knowledge and stand space at trade fairs with other Portuguese shoe manufacturers we work with. These collaborations have been very positive." "We also adapted solutions proposed by nearby suppliers and clients and offered them ideas in return. It's always mutually beneficial."</p>
		<p><b>D</b></p>	<p>"With some suppliers, including a Portuguese company and a German hemp fiber company, we co-developed innovative products for fairs and new collections, sharing prototypes and results." "We've shown our production monitoring software to over 50 companies at our supplier's request. I don't mind sharing best practices, it helps everyone evolve." "We collaborate closely with one or two Portuguese suppliers and a German hemp yarn company. We each make sample garments from their innovations for trade shows."</p>

Capability Building	Dynamic Capabilities	A	<p>"We made improvements... First, we replaced the dryer. The one we had didn't meet the capacity we needed. Then we upgraded the cooler, which helped us produce even higher quality pellets... Because if the pellet breaks during transport, that impacts our certification, it must have less than 0.5% fines. These upgrades strengthened our product and compliance." "We adapted along the way. With growing competition and technical challenges, we kept refining. I understand combustion deeply, I taught it. So when we faced user complaints, we didn't just change the product, we improved diagnostics and explained the underlying combustion science to our distributors." "I have a PhD in combustion and used to teach in this field. My technical knowledge helped us innovate effectively, even without much market information at the time."</p>
		B	<p>"When I took over the company in 2009, we were billing €1.2 million. Now it's €6.5 million — all thanks to improvements in quality, layout, productivity, and training."</p> <p>"We trained and empowered our workers. The idea is simple: the more you know, the more you earn. We encourage growth and initiative at every level."</p> <p>"We reorganized production by buying wheeled racks, rearranging machines, and timing operations. We now produce four times more glass with fewer people."</p>
		C	<p>"One of our strengths is rapidly developing diverse footwear types. We've grown from producing two to four product lines."</p> <p>"When we replaced outdated ovens, we saw an 80% drop in energy use, and this was a strategic resource reconfiguration."</p> <p>"We've kept some sustainable shoe models on the market for over a decade. We continue to adapt them, for example, aligning with the new 'barefoot' footwear trend."</p>
		D	<p>"Digitalizing production with custom software, installing automatic cutting systems, and continuous internal training, all helped us reconfigure the company for greater efficiency and sustainability."</p> <p>"We implemented company-wide digitalization, developed custom software, trained all staff—including adult education upgrades—and launched a continuous improvement program with Lean and 5S."</p>

Stakeholder Involvement in SOI	Knowledge Intermediaries	A	<p>“Eventually, I met someone who helped with funding applications. He asked if I had any ideas, and I shared this one. At that time, there was an open call from the Innovation Agency to create new clusters. So we drafted a proposal for a bioenergy cluster. That project got approved, and that’s how the journey began.”</p> <p>“Later, I also spoke with people to do research on certification. They're now helping us explore ways to validate our value chain and support a sustainability-driven marketing campaign. That’s part of our strategy now, to use certifications and partnerships to reinforce credibility.”</p>
		B	<p>"We are part of the Guardian Select network, an American multinational that sends us technical information and supports us with innovation. They are one of the main sources of our innovation."</p> <p>"Certifications, recognitions like PME Líder, and networks like COTEC are valuable, but there’s always a cost to accessing them. To access some of these networks and certifications, there are always fees, which is frustrating."</p>
		C	<p>“Our supplier ecosystem was key, we exchange solutions with them. They tested materials and we applied them in production.”</p> <p>“Certifications like GRS required us to install new systems fire exits, extraction vents, gas filters, forcing us to major changes advised by external auditors.”</p>
		D	<p>"We collaborate with CITEVE for product development contests, and their labs offer certifications and market studies that guide innovation."</p> <p>"Through CITEVE, we also validated sustainable materials and techniques that later became part of our production portfolio."</p>
SOI Outcomes	Green New Product (or Functionality) Development (NPD)	A	<p>"We ended up producing a pellet of superior quality. The improvements in equipment directly improved the usability and performance of the product, which is also reflected in our certifications."</p>
		B	<p>"I experimented artistically with fused glass, embedding bones, fish spines, plants. It was very creative and truly unique. Some of that work sells as jewelry or church windows."</p>
		C	<p>"We designed a best-selling flexible shoe using recycled leather and sole materials. It's been on the market for over 10 years."</p> <p>“We have shoes made from recycled leather and</p>

		recycled soles... and a barefoot model that's very successful in the new eco-market niche."
	<b>D</b>	"We developed an award-winning jacket that converts into a shopping bag, fully made from organic cotton, waterproof without the use of a internal membrane." "We consistently submit sustainable product innovations to the Hight Performance Textile Contest, often reaching the final stages."
Value Co-Creation with External Collaborators	<b>A</b>	"We worked with distributors to improve end-use. After the seminar, they could diagnose problems in boilers and educate customers. This mutual learning made a big difference."
	<b>B</b>	"We work closely with builders and clients. Sometimes, a client helps us understand what they really need. That input leads to better, customized solutions." "The Passivhaus certification we're moving towards is something we promote heavily with architects and builders, it requires collaboration."
	<b>C</b>	"We incorporated material ideas from suppliers and clients. Some became shared solutions used by multiple companies, not just ours." "Our best-selling products were co-conceived with clients looking for recycled solutions. They're still selling 10 years later."
	<b>D</b>	"We proposed joint product development initiatives with suppliers, like producing innovative prototypes using their newest sustainable raw materials." "We develop all showroom products in-house. One was a coat that transforms into a shopping bag, made from 100% organic cotton and waterproof without a membrane."
Enhanced Brand Legitimacy & Market Expansion	<b>A</b>	"With certiications we want to promote what makes us different, local investment, sustainability, job creation. That's a message that adds value and builds trust in our brand." "We invested in Portugal and helped value the pine value chain... and now we compete with cheap imports from deforestation overseas. We're working on a campaign to show our added value and sustainability."

		<p><b>B</b></p> <p>"We've won the COTEC Innovation Award and have been PME Líder since 2015. These recognitions help build trust with clients and institutions." "Houses with the Passivhaus certification can sell for 40% more. We're aiming to provide the type of glass that supports that standard that's our niche."</p>
		<p><b>C</b></p> <p>"Without our work in sustainable footwear, we might not exist today. It brought us visibility and made us a reference in Portugal." "Some sustainable models have lasted over a decade, that's rare in fashion, and it shows our brand recongnition."</p>
		<p><b>D</b></p> <p>"Our certifications, STeP and GOTS, and award-winning innovations significantly improved our visibility and prestige in markets like Germany, Switzerland, and the Nordics."</p>
		<p><b>B</b></p> <p>"There are very few people who truly love what they do. Most just want a job to pay bills. Finding skilled, motivated workers is a real challenge." "We invested a lot in basic training—people come with no awareness of safety or productivity. Schools don't prepare them for this industry."</p>
		<p><b>C</b></p> <p>"One of the main current challenges is the lack of qualified, or even unqualified, labor to work in the footwear industry."</p>
		<p><b>D</b></p> <p>"Attracting young, qualified labor remains extremely difficult, but thanks to digitalization and internal training, we've managed to rejuvenate our workforce. Around 25% of our workforce is under 30 years old." "Our sector has no training schools. People undervalue factory work. That's why we internally upgraded staff education and digital skills."</p>
	Market Volatility & Financial Uncertainty	<p><b>A</b></p> <p>"I just heard that traders are importing pellets from across the Atlantic. The market is flooded, and we're competing with producers that have entirely different cost structures and values. It's a major threat." "The industry is in crisis right now. Many factories are shutting down. We're dealing with excess capacity and price wars, which is making it hard for sustainable producers to stay viable."</p>
		<p><b>B</b></p> <p>"We could be billing even more if we chased the market, but I prefer to sleep at night knowing we didn't cut corners." "The system is tough. In Portugal, companies like ours face more difficulty... certifications are expensive, and Chinese imports without CE flood the market."</p>

		<b>C</b>	"A recent challenge has been the delays in payment from clients, though it hasn't reached critical levels, it's becoming more frequent."
		<b>D</b>	"Despite many achievements, crises like COVID-19 and international instability constantly threaten investment capacity and increase operational uncertainty."
	Concerns Over Knowledge Spillovers	<b>A</b>	"Eventually, our competitors also accessed this knowledge, and they benefited from it... But that's one of the risks of open innovation, once any specific knowledge spreads, it's no longer a competitive advantage."
		<b>C</b>	"Despite the industry association being conservative, we still share what's needed... we don't feel threatened by competitors because the market is huge."
		<b>D</b>	"Most companies still live in their own 'little castles', afraid to share anything out of fear of losing clients or leaking knowledge. I don't share that view, I think best practices must be shared." "Despite my openness, the lack of collaboration culture, both from companies and even local institutions, shows how afraid many still are of spillovers." "Our best partnerships come from open-minded suppliers—unlike many Portuguese associations, which remain closed off in their 'little kingdoms.'"